Induction to the SPPC Study

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for the SPPC study group

Snowmass 2020 - Joint AF-EF Meeting on Future Colliders
June 24, 2020, Video Meeting

Outline

- Science goals
- Main parameters or performance
- Design features and R&D efforts
- Summary

Physics goal at SPPC

- New physics in energy frontier
  - Discover an entirely new set of particles in the O(10 TeV) regime, and unveil new fundamental physics principles.
  - One of the most exciting opportunities is to address the naturalness problem. The naturalness problem stems from the vast difference between two energy scales: the currently probed electroweak scale and a fundamental scale, such as the Planck scale.
  - Dark matter: Weakly interacting massive particles (WIMPs)
  - The electroweak symmetry and flavor symmetry will be restored at the SPPC energy
- Higgs physics:
  - Higgs physics will be largely explored by CEPC, but SPPC will provide higher precision measurements in such as rare decay channels and Higgs potential form.

SPPC main parameters

Parameter	Unit	Value		
		PreCDR	CDR	Ultimate
Circumference	km	54.4	100	100
C.M. energy	TeV	70.6	75	125-150
Dipole field	T	20	12	20-24
Injection energy	TeV	2.1	2.1	4.2
Number of IPs		2	2	2
Nominal luminosity per IP	$cm^{-2}s^{-1}$	1.2e35	1.0e35	-
Beta function at collision	m	0.75	0.75	-
Circulating beam current	A	1.0	0.7	-
Bunch separation	ns	25	25	-
Bunch population		2.0e11	1.5e11	-
SR power per beam	MW	2.1	1.1	-
SR heat load per aperture @arc	W/m	45	13	-

Collider Accelerator Physics

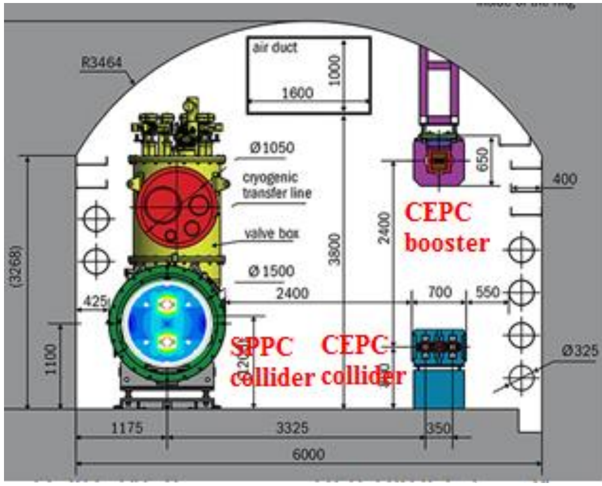
-Parameter list

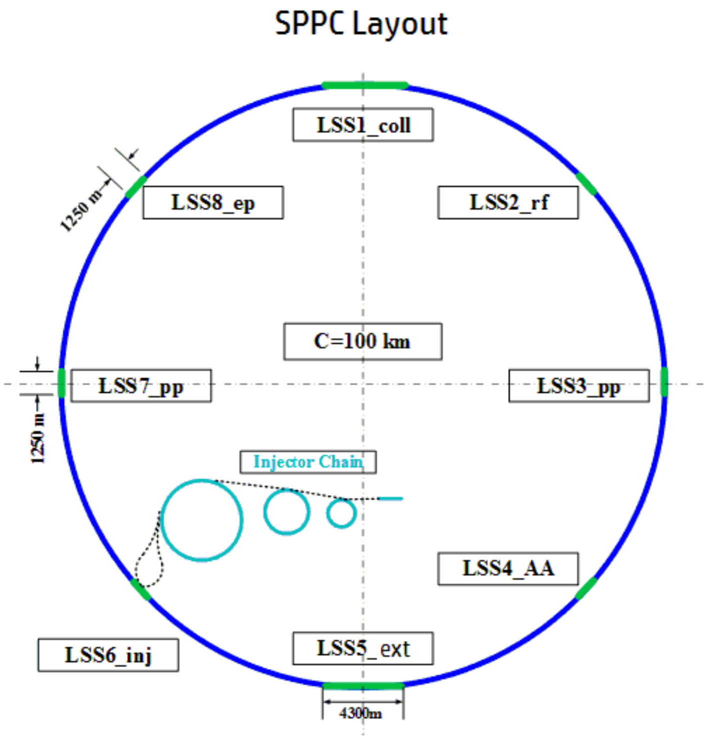
Parameter	Value	Unit
Main parameters		
Circumference	100	km
Beam energy	37.5	TeV
Lorentz gamma	39979	
Dipole field	12.00	T
Dipole curvature radius	10415.4	m
Arc filling factor	0.780	
Total dipole magnet length	65442.0	m
Arc length	83900	m
Total straight section length	16100	m
Energy gain factor in collider rings	17.86	
Injection energy	2.10	TeV
Number of IPs	2	
Revolution frequency	3.00	kHz
Revolution period	333.3	µs
Physics performance and beam parameters		
Nominal luminosity per IP	1.01E+35	$cm^{-2}s^{-1}$
Beta function at initial collision	0.75	m
Circulating beam current	0.73	A
Nominal beam-beam tune shift limit per	0.0075	
Bunch separation	25	ns
Bunch filling factor	0.756	
Number of bunches	10080	
Bunch population	1.5E+11	
Accumulated particles per beam	1.5E+15	
Normalized rms transverse emittance	2.4	µm
Beam life time due to burn-off	14.2	hour
Turnaround time	3.0	hour
Total cycle time	17.2	hour

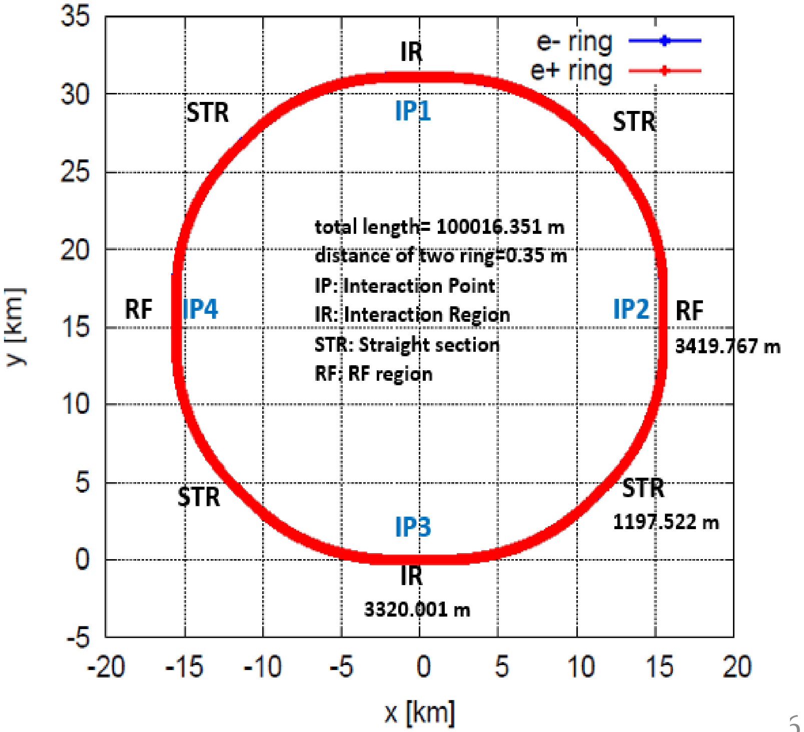
Total / inelastic cross section	147	mbarn
Reduction factor in luminosity	0.85	
Full crossing angle	110	µrad
rms bunch length	75.5	mm
rms IP spot size	6.8	µm
Beta at the 1st parasitic encounter	19.5	m
rms spot size at the 1st parasitic encoun	34.5	µm
Stored energy per beam	9.1	GJ
SR power per ring	1.1	MW
SR heat load at arc per aperture	12.8	W/m
Critical photon energy	1.8	keV
Energy loss per turn	1.48	MeV
Damping partition number	1	
Damping partition number	1	
Damping partition number	2	
Transverse emittance damping time	2.35	hour
Longitudinal emittance damping time	1.17	hour

Tunnel compatible between CEPC and SPPC

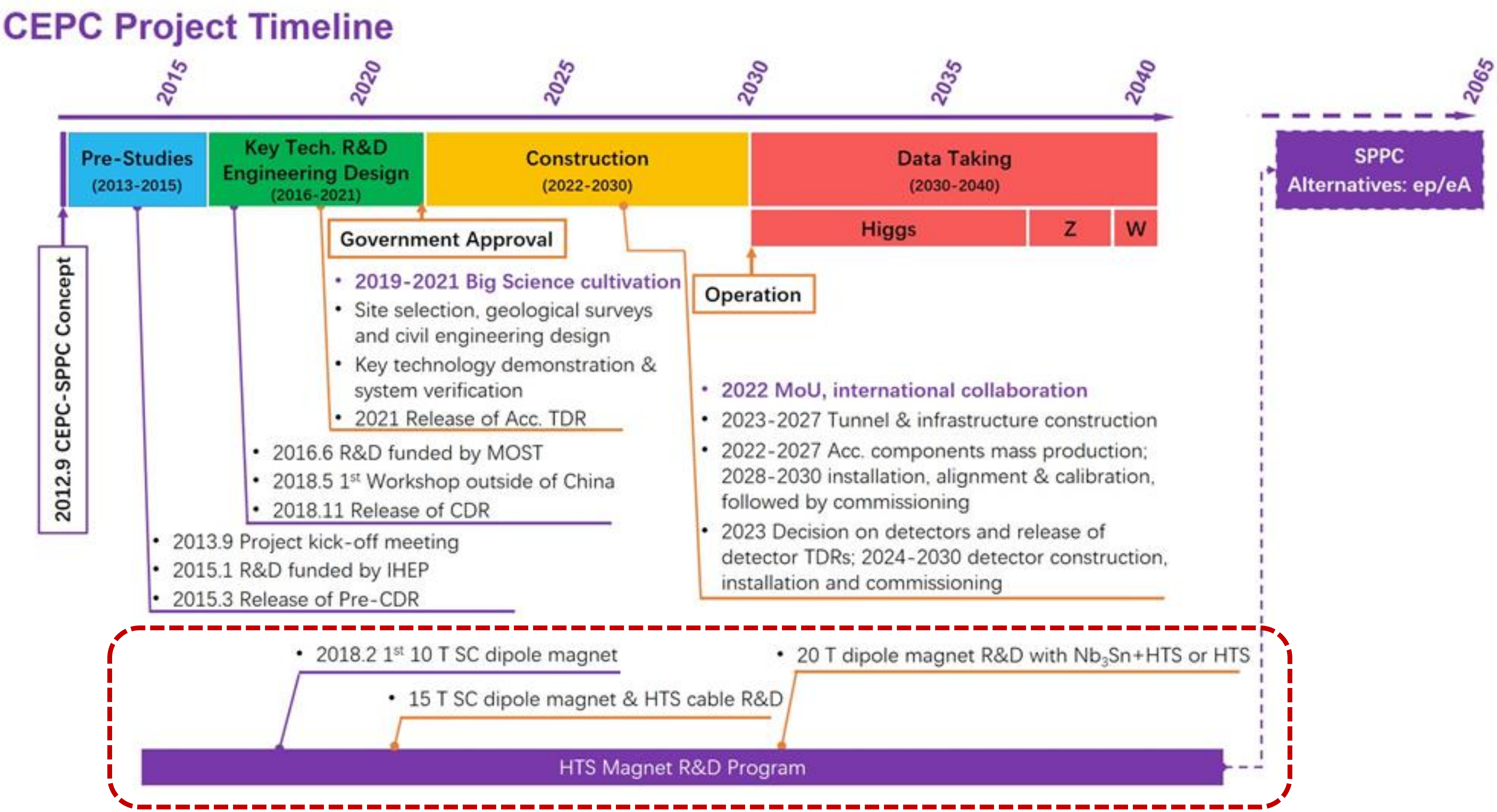
- Eight-fold lattice accepted by both CEPC and SPPC
- Very challenging if the tunnel accommodates both the colliders in the same time







CEPC-SPPC Project Timeline

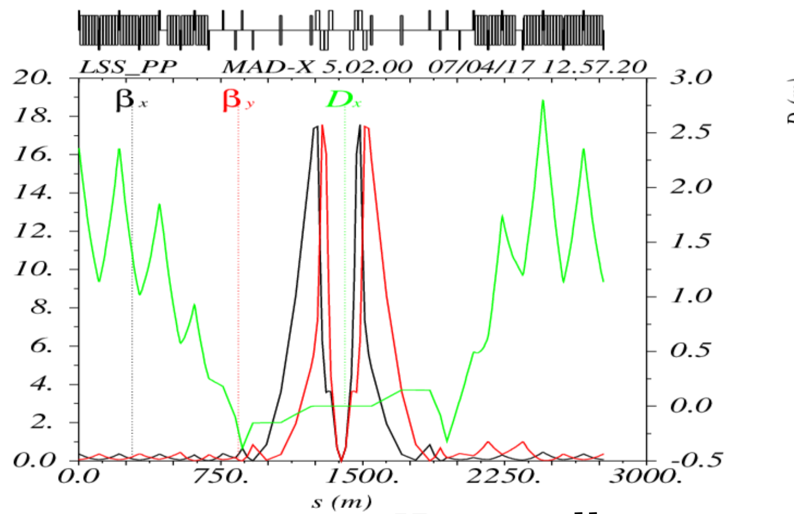


Accelerator Physics

- Studying challenging problems and possible solutions
- Main efforts have been on (small team)
  - Lattice, layout, dynamics aperture
  - Beam collimation
  - Beam-beam effects, luminosity optimization and leveling
  - Longitudinal dynamics (collider and injector chain)
  - Instabilities
  - Injector chain concept design

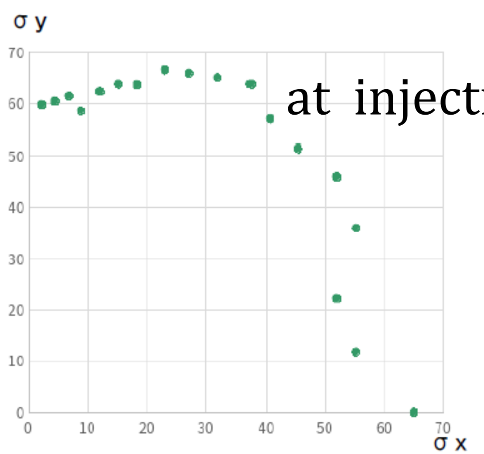
Lattice design and dynamic aperture

- Different lattice designs
  - Different schemes (100 TeV and 75 TeV @100 km)
  - IP Lattice at collision and injection
  - Compatibility between CEPC and SPPC
  - Arc cells, Dispersion suppressors, insertions

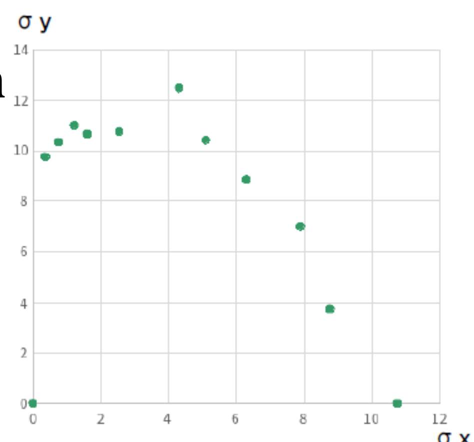


IP: at collision

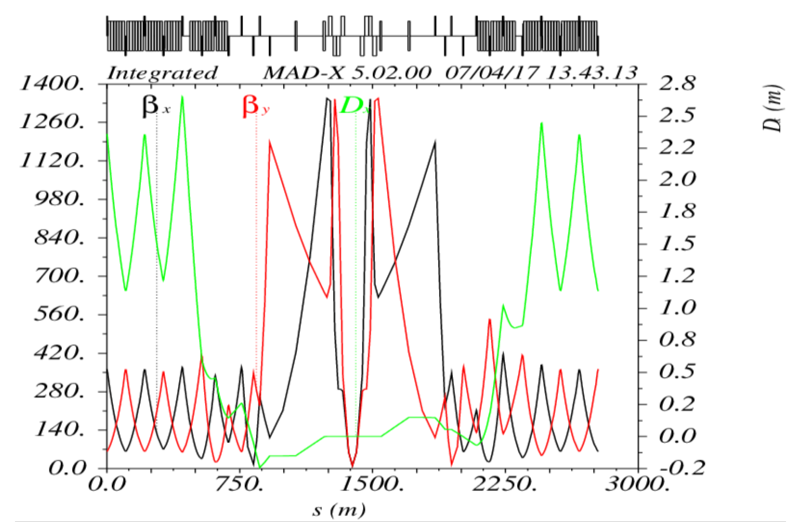
at injection



Adding sextuple without dipole error (chromaticity corrected)



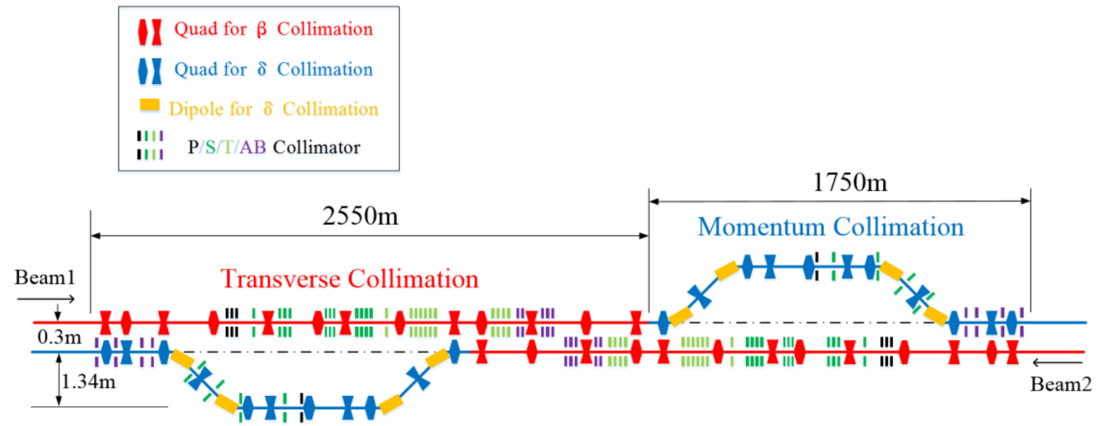
Adding sextuple and dipole error (chromaticity corrected)

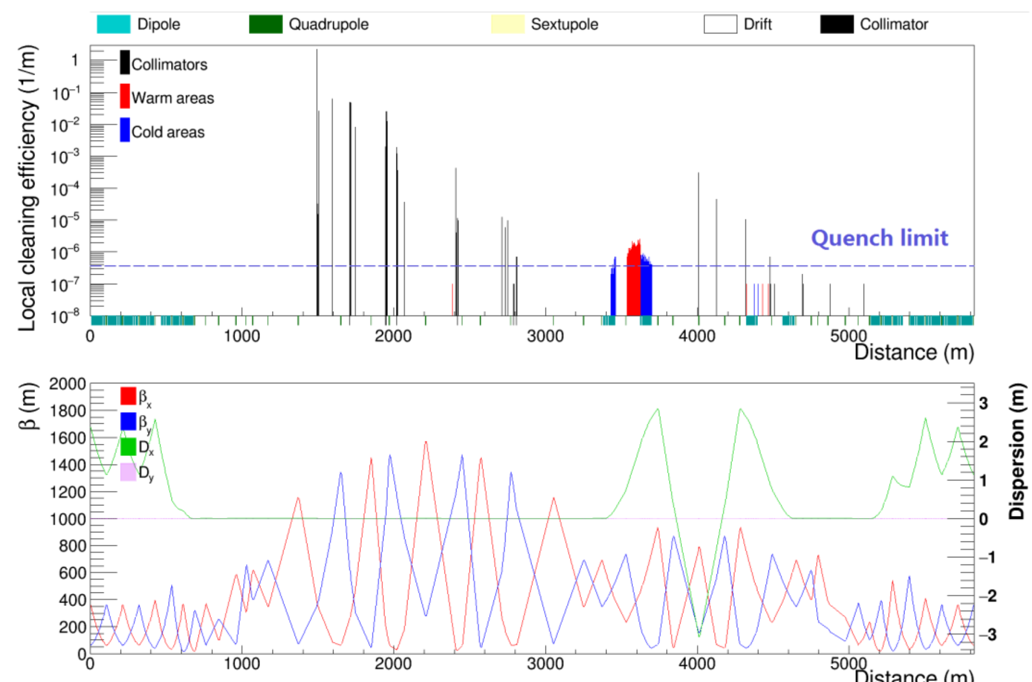


IP: at injection

Beam Collimation

- To tackle the huge stored energy, 9 GJ/beam
  - SPPC has adopted a combined collimation method by arranging the transverse and longitudinal collimation in one long straight section
  - Five-stage collimation with special SC quads in the transverse collimation



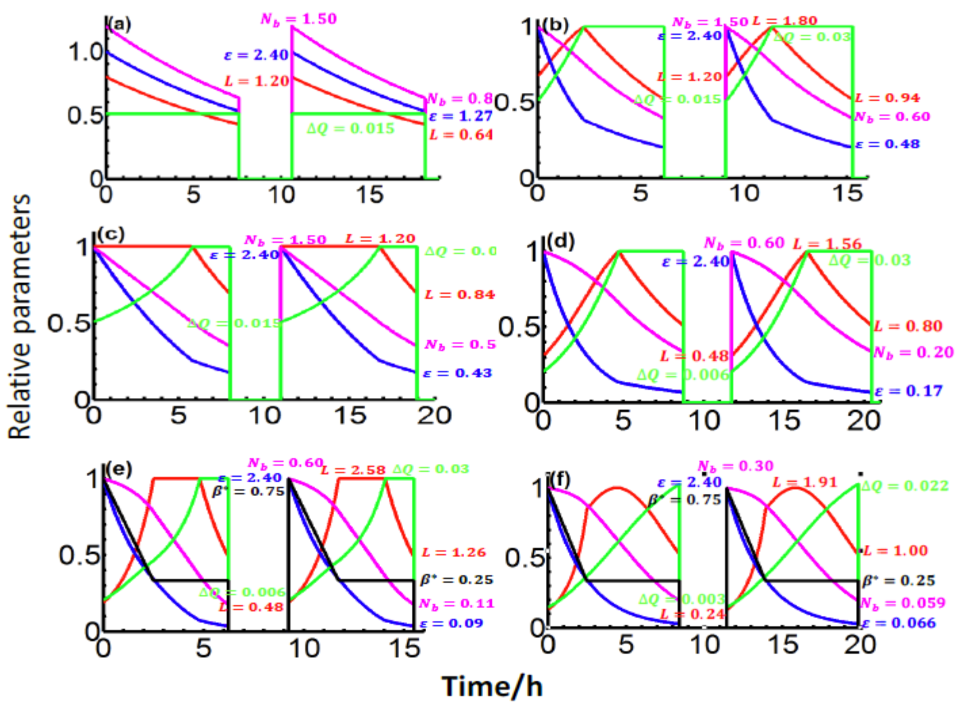


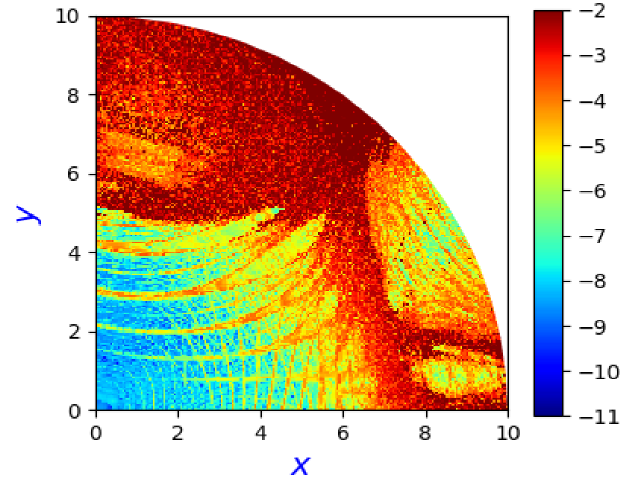
(b)

J.Q. Yang, PRAB 22, 023002 (2019)

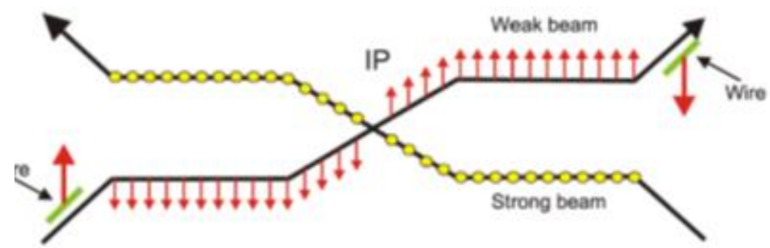
Beam-beam effects, and luminosity leveling

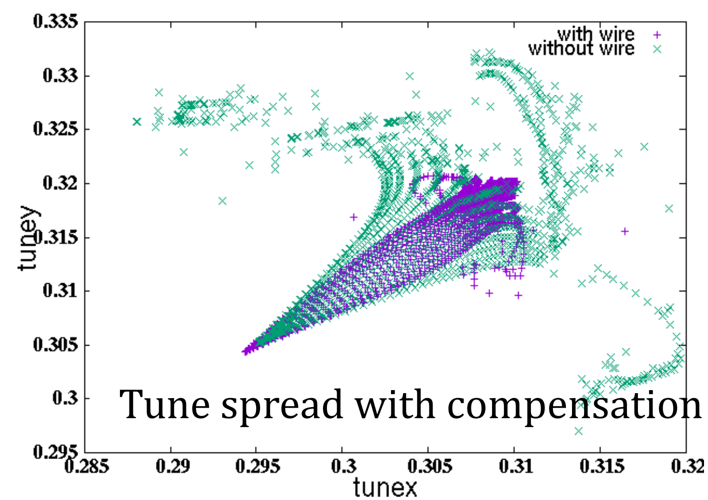
- Beam dynamics about beam-beam effects
  - Head-on interaction, Long-range interaction, Orbit effects
  - Beam-beam compensation schemes
- Luminosity levelling





Sextupole + head-on + long-range

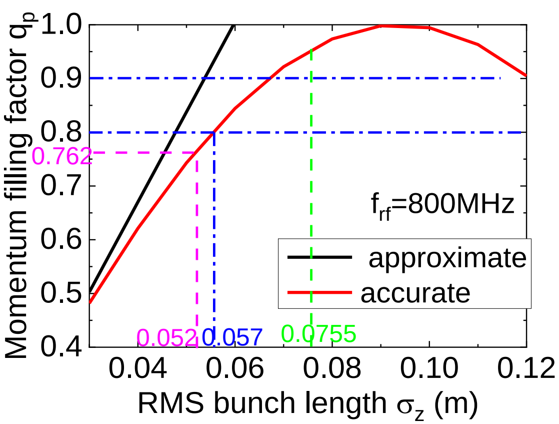




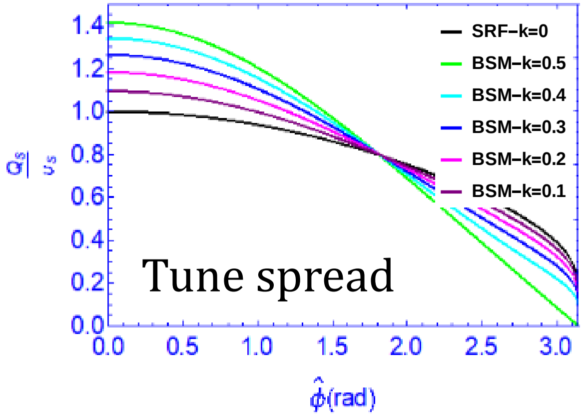
Longitudinal beam dynamics

- RF parameters in the accelerator chain (five stages)
- Bunch filling scheme in SPPC
- To enhance Landau damping or mitigate longitudinal instabilities, a large spread in synchrotron frequency inside the bunch is required.
  - ➢ use a higher harmonic cavity (800MHz RF cavity)
  - ➢ Dual harmonic RF system
  - ➢ Controlled emittance blow-up

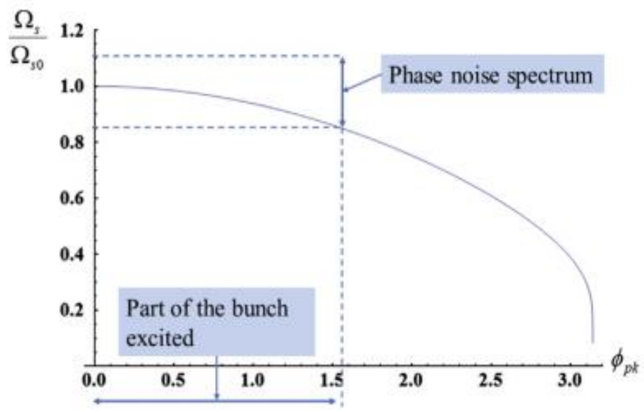
800 MHz RF system



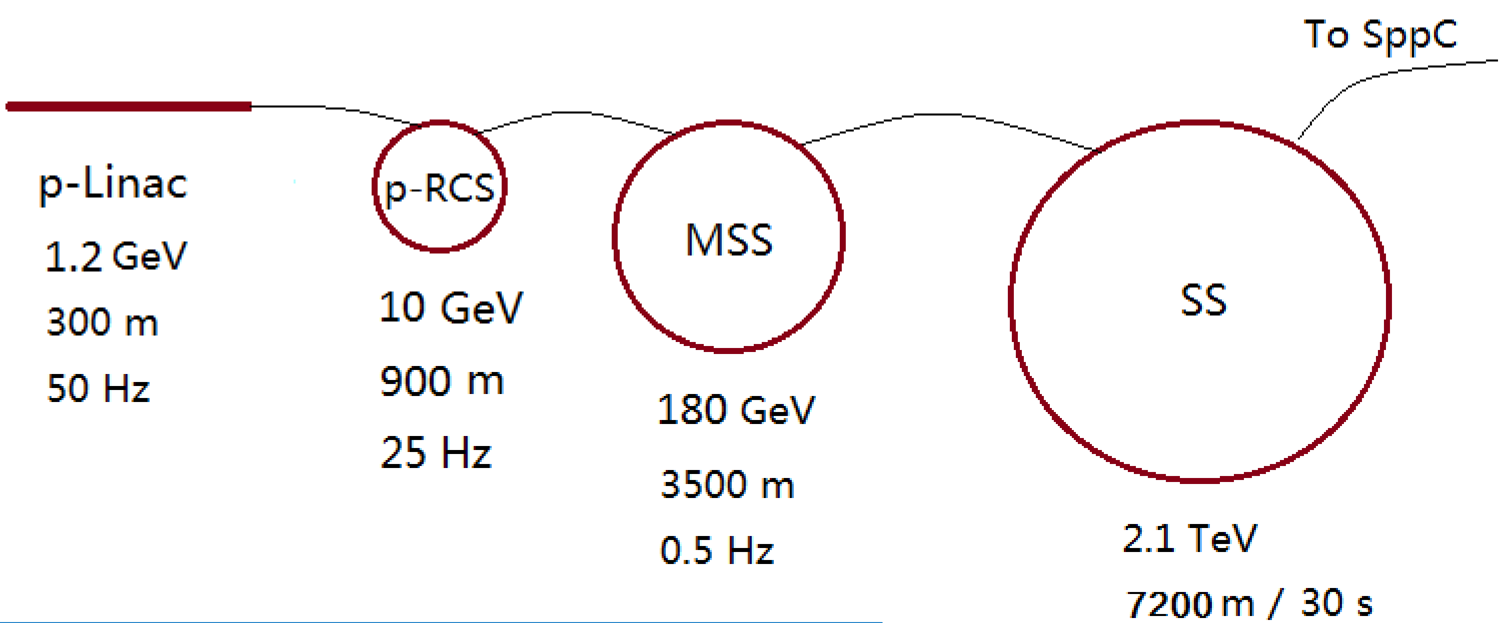
Dual-harmonic RF (400MHz+800MHz)



Controlled emittance blowup



Injector chain
(for proton beam)



p-Linac: proton superconducting linac

p-RCS: proton rapid cycling synchrotron

MSS: Medium-Stage Synchrotron

SS: Super Synchrotron

Ion beams have dedicated linac (I-Linac) and RCS (I-RCS)

Major parameters for the injector chain

	Value	Unit		Value	Unit
p-Linac			MSS		
Energy	1.2	GeV	Energy	180	GeV
Average current	1.4	mA	Average current	20	uA
Length	~300	m	Circumference	3500	m
RF frequency	325/650	MHz	RF frequency	40	MHz
Repetition rate	50	Hz	Repetition rate	0.5	Hz
Beam power	1.6	MW	Beam power	3.7	MW
p-RCS			SS		
Energy	10	GeV	Energy	2.1	TeV
Average current	0.34	mA	Accum. protons	1.0E14	
Circumference	970	m	Circumference	7200	m
RF frequency	36-40	MHz	RF frequency	200	MHz
Repetition rate	25	Hz	Repetition period	30	s
Beam power	3.4	MW	Protons per bunch	1.5E11	
			Dipole field	8.3	T

High power modes for p-Linac, p-RCS and MSS are for off-SPPC applications

Technical Challenges

- There are many technological challenges in building future p-p colliders, among them the most crucial is high-field SC magnets
  - Currently the only R&D effort for SPPC, supported by a CAS research program to promote high-temperature superconducting technology, which involves different CAS institutions and also some companies (IHEP group led by Q.J. Xu)
  - Study on the beam screen not continued

Performance of the 1st IBS Solenoid Coil

Fabrication and test of IBS solenoid coil at

IOP Publishing Superconductor Science and Technology
Supercond. Sci. Technol. 32 (2019) 04LT01 (5pp) https://doi.org/10.1088/1361-6668/ab09a4

Letter

First performance test of a 30 mm iron-based superconductor single pancake coil under a 24 T background field

Dongliang Wang[1,2,5], Zhan Zhang[3,5], Xianping Zhang[1,2], Donghui Jiang[4], Chiheng Dong[1], He Huang[1,2], Wenge Chen[4], Qingjin Xu[3,6] and Yanwei Ma[1,2,6]

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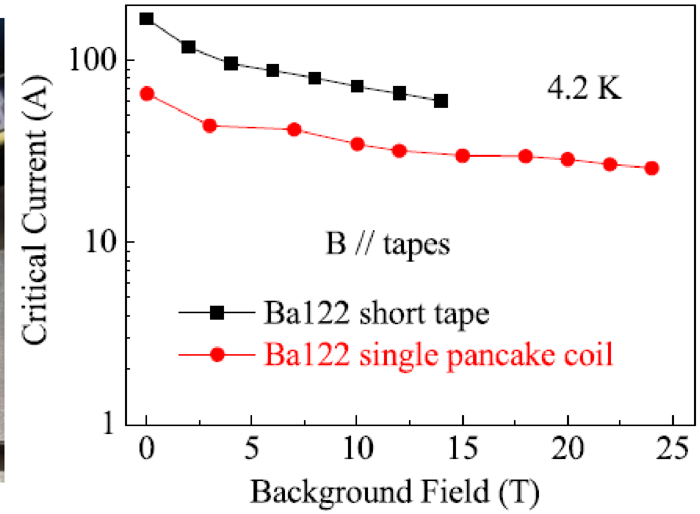

Viewpoint by NHMFL

'From a practical point of view, **IBS are ideal candidates for applications**. Indeed, some of them have quite a **high critical current density, even in strong magnetic fields**, and a low superconducting anisotropy.

Moreover, **the cost of IBS wire can be four to five times lower than that of Nb_3Sn**……

IOP Publishing Superconductor Science and Technology
Supercond. Sci. Technol. 32 (2019) 070501 (3pp) https://doi.org/10.1088/1361-6668/ab1fc9

Viewpoint

CrossMark

Constructing high field magnets is a real tour de force

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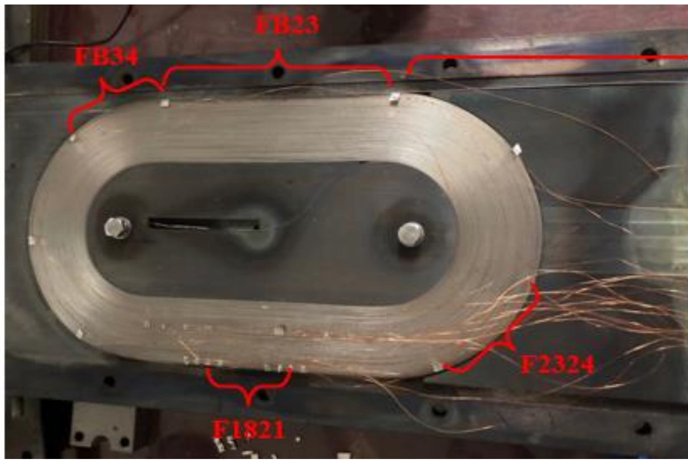
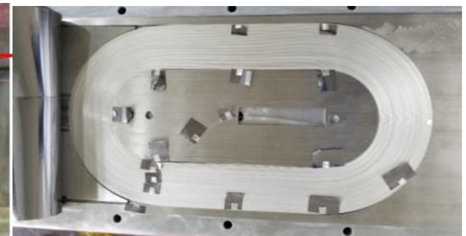
This is a viewpoint on the letter by Dongliang Wang *et al* (2019 *Supercond. Sci. Technol.* 32 04LT01).

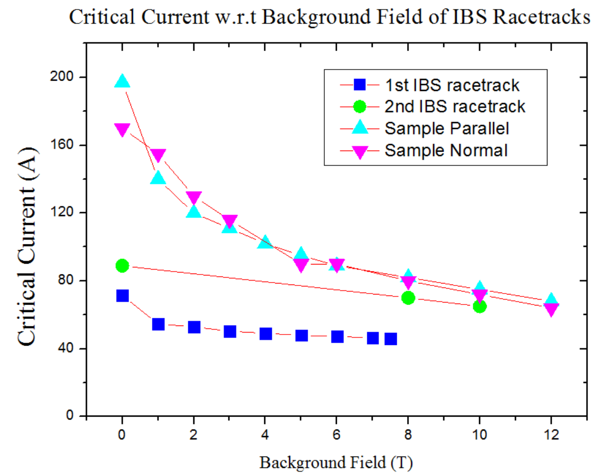
Following the discovery of superconductivity in 1911, Heike Kamerlingh Onnes foresaw the generation of strong magnetic fields as its possible application. He designed a 10 T electromagnet made of lead–tin wire, citing only the difficulty

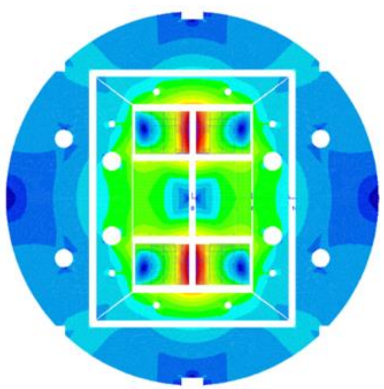
Test of the 1st IBS Racetrack Coil at 10T

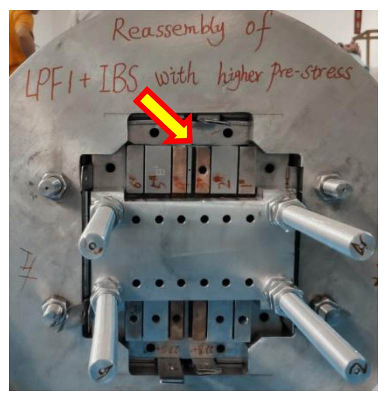
- ***Two racetrack coils with 100m long IBS tapes have been fabricated and tested at 10T background field.***
- ***Ic in the coil reached 86.7% of the short sample at 10T.***

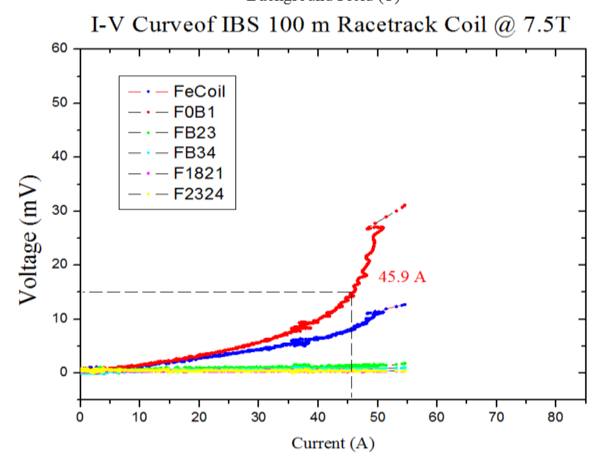






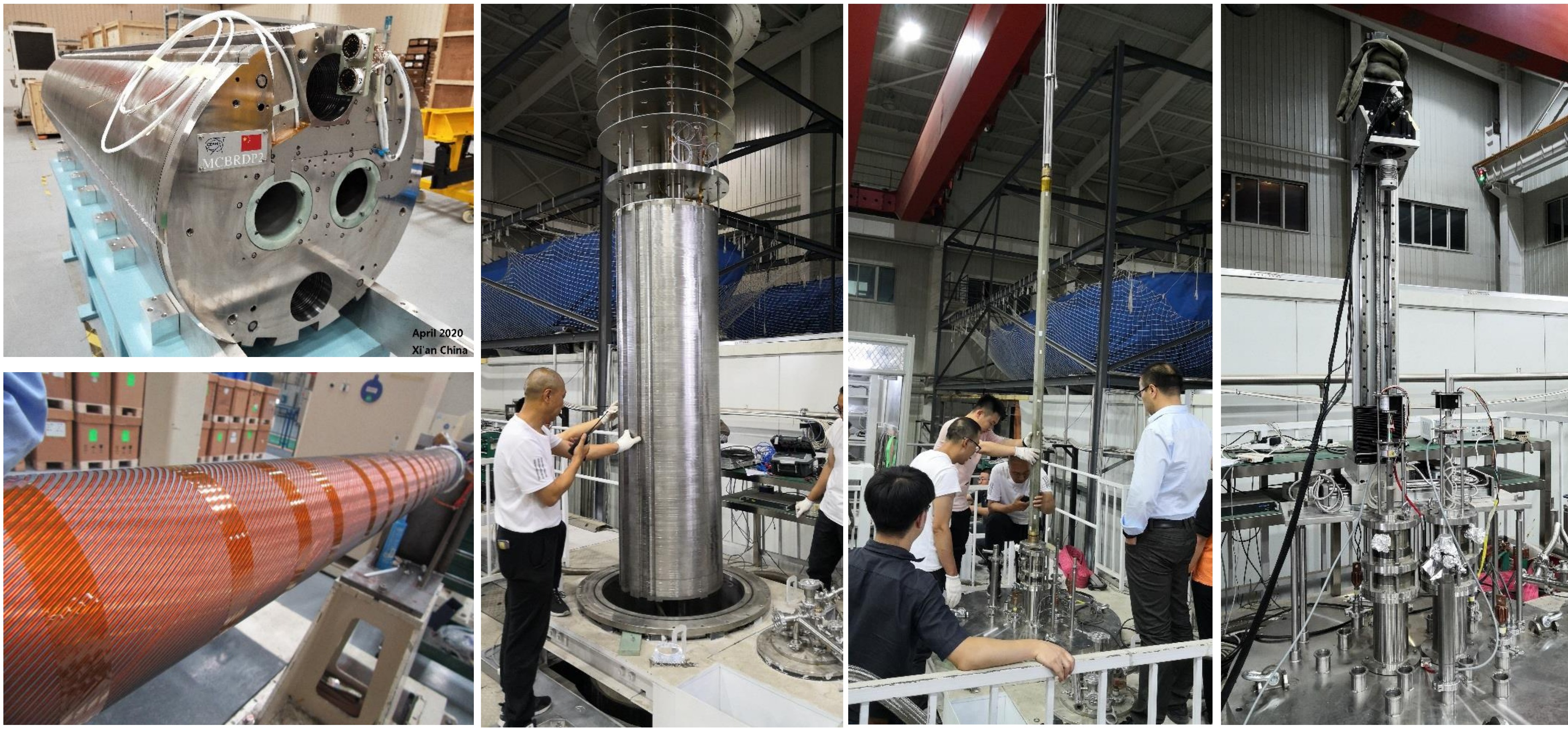






R&D of HL-LHC CCT Magnets

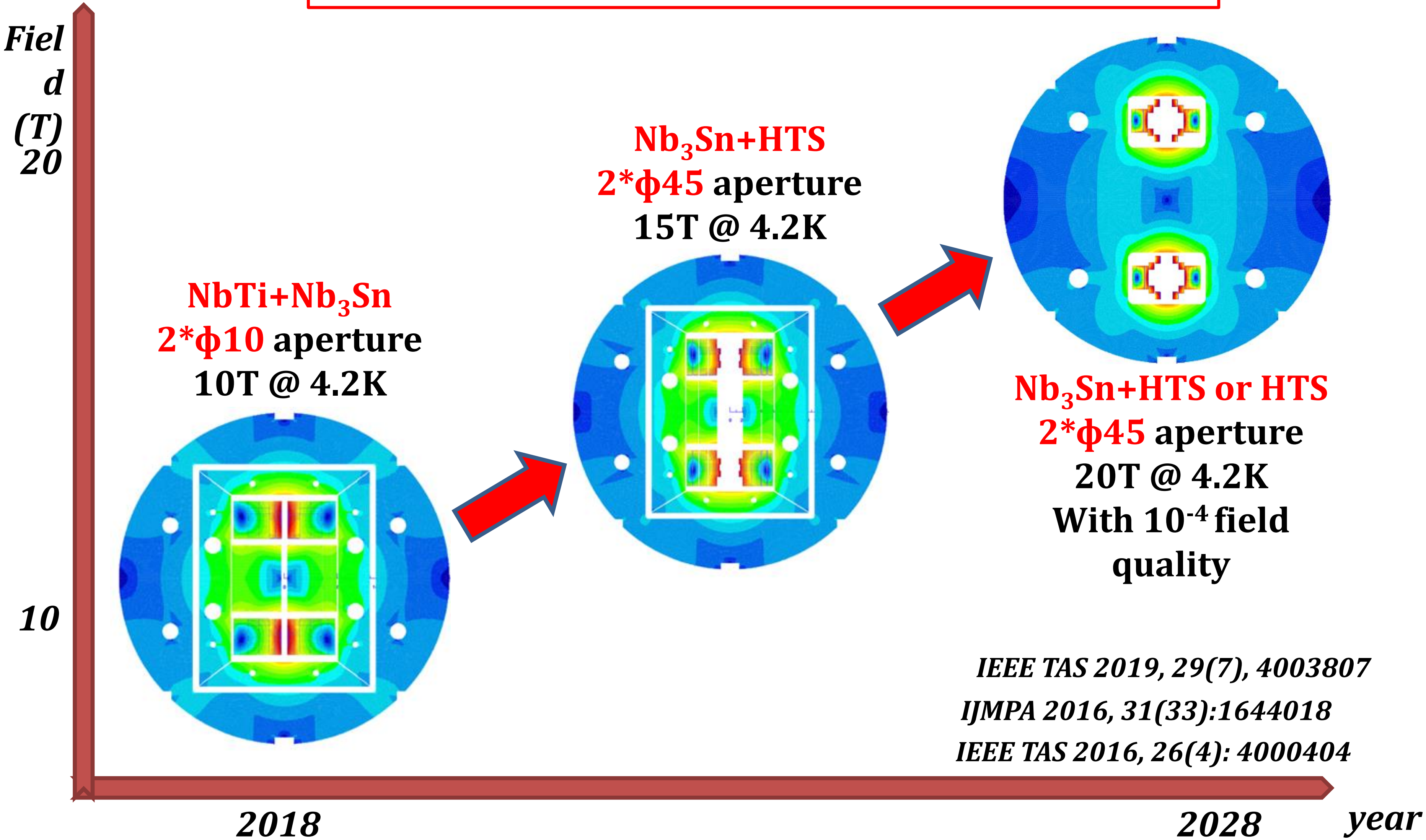
2.2m prototype fabrication completed, being tested now at IMP, and to be delivered to CERN by July 2020. Mass prodution to be started soon.



Fabrication and test of the 2.2m prototype CCT Magnet

R&D Roadmap for the next years

SPPC dipole field: baseline 12 T, optimum 20-24T



Summary

- SPPC study at a low profile to follow the CEPC study, from Pre-CDR, CDR and towards TDR
- Special emphasis on key accelerator physics problems and compatibility between CEPC and SPPC
- R&D efforts on high-field SC magnets is supported in a wider national effort to promote high-temperature superconducting technology

Thank you for your attention!